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Laboratory Evaluation of Quartz Dust Capture of Irrigated-Filter Collection Systems for Continuous Miners

By J. F. Colinet, J. J. McClelland, L. A. Erhard, and R. A. Jankowski

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Report of Investigations 9313

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**UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary**

**BUREAU OF MINES
T S Ary, Director**

Library of Congress Cataloging in Publication Data:

Laboratory evaluation of quartz dust capture of irrigated-filter collection systems for continuous miners / by J.F. Colinet . . . [et al.].

p. cm. -- (Report of investigations / Bureau of Mines, United States Department of the Interior; 9313)

Includes bibliographical references (p.).

Supt. of Docs. no.: I 28.23:9313.

1. Coal mines and mining--Dust control. 2. Quartz dust. 3. Air filters. I. Colinet, Jay. II. Series: Report of investigations (United States. Bureau of Mines); 9313.

TN23.U43 [TN312] 622 s-dc20 [622'.83] 90-1808 CIP

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

fpm	foot per minute	mg	milligram
ft	foot	mg/m ³	milligram per cubic meter
ft ³ /min	cubic foot per minute	mm	millimeter
gal	gallon	μm	micrometer
gpm	gallon per minute	min	minute
h	hour	pct	percent
in	inch	psi	pound (force) per square inch
in H ₂ O	inch of water	s	second
lb	pound	vol pct	volume percent

LABORATORY EVALUATION OF QUARTZ DUST CAPTURE OF IRRIGATED-FILTER COLLECTION SYSTEMS FOR CONTINUOUS MINERS

By J. F. Colinet,¹ J. J. McClelland,¹ L. A. Erhard,² and R. A. Jankowski³

ABSTRACT

The U.S. Bureau of Mines conducted a series of laboratory tests in a full-scale model to determine the respirable quartz dust capture efficiency of an irrigated-filter collection system while testing different filter densities, different filter materials, preconditioning water sprays, and wetting additives in the spray water. Impactor samplers were operated upstream and downstream of the filter unit to determine overall dust collection efficiency. The impactor filters containing the 0.7- to 4.7- μm size fractions were analyzed for quartz content, and these data were used to calculate quartz dust collection efficiency.

The results of this testing indicated that (1) increased filter density improved quartz dust collection, but also resulted in a significant increase in pressure drop across the filter, (2) an alternate synthetic filter material improved dust collection without increasing pressure drop, (3) preconditioning sprays mounted in the system ductwork can have a beneficial effect on dust collection, and (4) additives to the spray water did not significantly increase dust collection.

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INTRODUCTION

In recent years, the number of entities in coal mines required to operate under a more stringent dust standard because of the presence of excessive levels of quartz in the respirable dust has dramatically increased from 329 in 1981 to over 1,940 in 1989. Improvements in the quartz analysis and monitoring program utilized by the U.S. Mine Safety and Health Administration (MSHA) contributed significantly to this marked increase. The severity of the quartz compliance problem has prompted the U.S. Bureau of Mines to focus research efforts into finding improved methods for controlling worker exposure to respirable quartz dust.

One approach for controlling respirable quartz dust is to utilize control techniques that have been successful on coal dust and determine their success for quartz dust. Modifications to these control techniques should also be considered. One such control technique for use on continuous miners is the flooded-bed scrubber. The flooded-bed scrubber pulls dust-laden air from the mine face area and passes this air through a filter panel being wetted by water sprays mounted in the scrubber ductwork. The

dust-laden water exiting the filter is removed from the airstream by a mist eliminator and discharged onto the continuous miner conveyor. The clean, dry air is then discharged toward the face return.

Previous Bureau research⁴ has shown the flooded-bed scrubber to be over 90 pct efficient in removing respirable coal dust that enters the scrubber unit. No prior work has specifically examined the scrubber's ability to remove quartz dust.

Consequently, the goal of this research effort was to determine the respirable quartz dust collection efficiency for a typical flooded-bed scrubber unit operating with a standard filter panel. The standard panel in use by the coal industry is constructed from layers of fine stainless steel mesh held between two perforated stainless steel plates. Modifications to the standard filter system were made, and subsequent testing was conducted to investigate alternate filter materials and/or methods to improve quartz dust collection. This work was done by the Bureau to enhance health and safety of the mine worker.

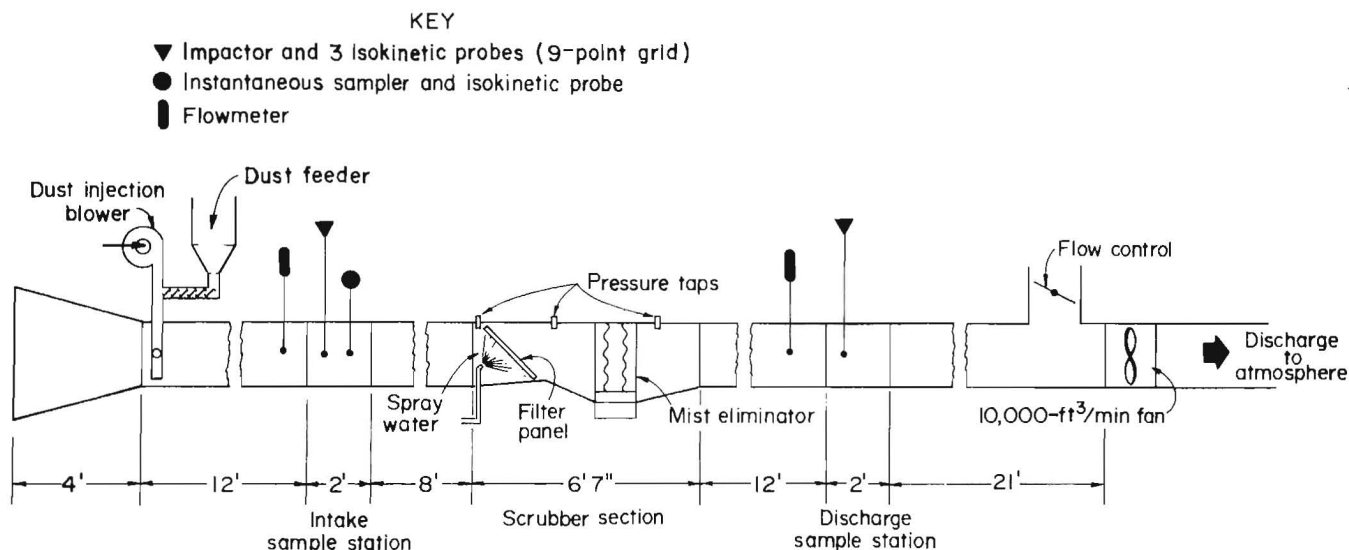
FULL-SCALE TEST FACILITY

A test unit was constructed at the Bureau's Pittsburgh Research Center consisting of a dust injection system, associated ductwork with sampling stations, a scrubber section, and a fan (fig. 1). The full-scale model of a flooded-bed scrubber was fabricated from steel plate, complete with a spray bar, a filter holder, and a mist eliminator identical to those used on the

Joy⁵ 14CM continuous miner. The filter section and mist eliminator of the full-scale model are shown in figure 2.

⁴Divers, E. F., and J. T. Janosik. Scrubbers for Dust Control: A Comparison of Six Medium-Energy Use Types. BuMines RI 8449, 1980, 29 pp.

⁵Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.



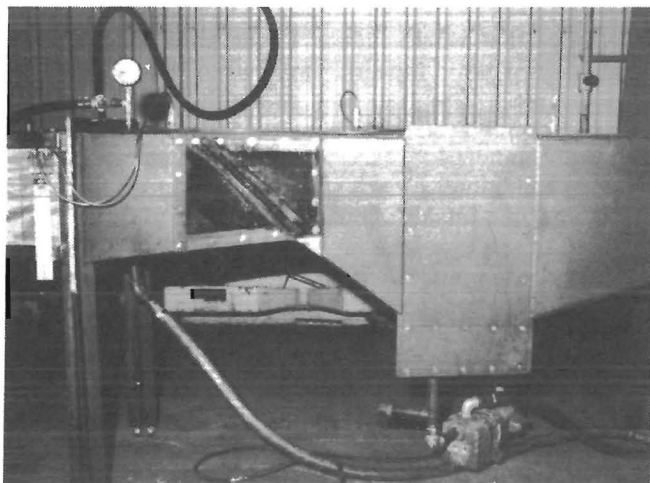


Figure 2.—Full-scale model of filter section and mist eliminator.

The spray bar contained three Spraying Systems Co. HH9.5 hollow-cone water sprays that were positioned so that the entire surface area of the scrubber filter would be wetted and washed by the sprays. The filter panel was positioned on a 45° angle into the airflow. The cover plate at the filter holder was enlarged and fabricated from clear Plexiglas acrylic sheet so that the filter and water sprays could be observed throughout testing. A wave-blade mist eliminator was located immediately downstream of the filter panel; this eliminator removed the majority of the water from the discharge airstream. A small sump and water pump that continually discharged the dust-laden water from the unit were located beneath the mist eliminator.

Static pressure taps were installed on the upstream and downstream sides of the filter panel and also on the downstream side of the mist eliminator. Tygon rubber tubing connected the pressure taps on each side of the filter panel to a U-tube manometer, which was used to measure the differential pressure across the filter. Differential pressure readings were obtained at the beginning and end of each test.

A pressure gauge and regulator were installed in the water feed line at the scrubber inlet to monitor and control water pressure to the sprays. The water pressure was checked periodically throughout each test to ensure that proper pressure and flow were maintained.

The remaining sections of the test facility were fabricated from plywood bolted to angle iron framework. All joints were sealed with caulking compound to minimize leakage.

At the inlet of the test unit, a special 4-ft-long section of ductwork was fabricated with a 4-to-1 reduction in cross-sectional area. This reducer section provided more consistent flow and acceleration of the inlet air as the air entered the scrubber ductwork.

The dust injection system, located at the end of the inlet reducer, contained a dust feeder, an auxiliary blower, and a cross-shaped injection manifold. An adjustable screw

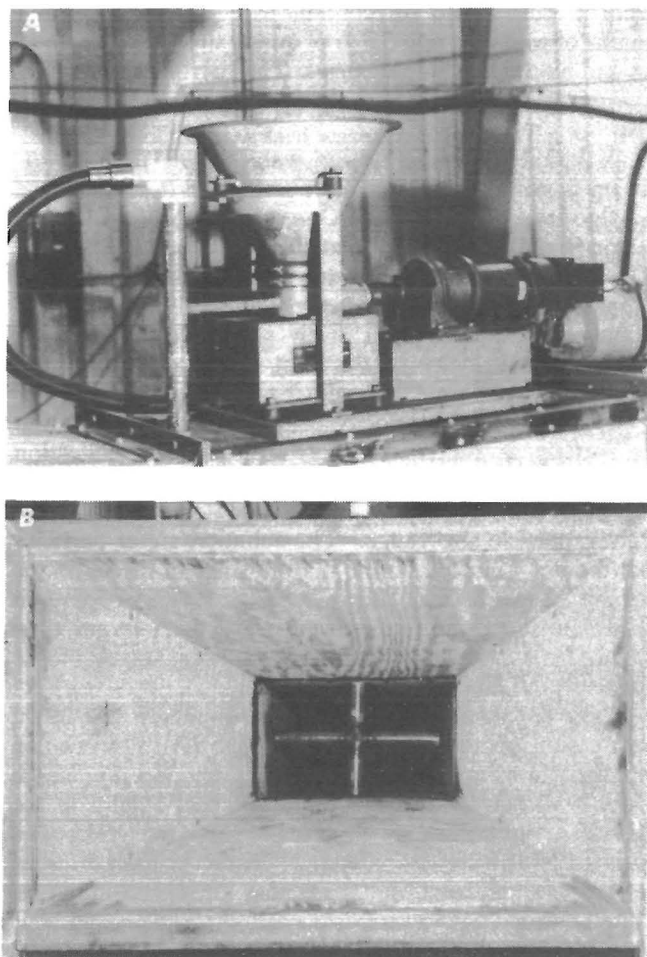


Figure 3.—Dust injection system for test facility. A, Screw feeder and auxiliary blower; B, dust injection manifold positioned in inlet duct.

feeder (fig. 3A) was used to supply feed dust for each test. The feed rate was checked periodically throughout the test program to monitor feeder performance. The feeder discharged into the vertical pipe leading to the dust injection manifold. The manifold (fig. 3B) was fabricated from 1-1/2-in polyvinyl-chloride pipe with two rows of discharge holes located on each of the four sections of the manifold. With the assistance of an auxiliary blower, the dust was dispersed through the manifold and entrained by the airflow in the duct. Over the series of tests, the respirable dust concentration on the intake side of the filter was maintained at approximately 100 mg/m³.

The feed dust was a blend of bituminous coal and silica containing approximately 10 pct silica (quartz) by weight. The coal and quartz were commercially ground products purchased from outside vendors. Table A-1 in the appendix contains the size distribution for each product as determined by Coulter counter analysis at an independent laboratory. These data show that the coal and quartz dusts were nominally minus 50 μ m, which is representative of

airborne dust found on continuous miner faces. Fifty pounds of coal dust and 5.5 lb of quartz dust were weighed out and placed in a 30-gal barrel. The barrel was mounted in a mixer and rotated to produce a well-blended feed dust.

An intake sampling station was located 12 ft downstream from the dust injection point and 8 ft upstream of the flooded-bed scrubber. One Andersen Mark II impactor (fig. 4) was operated at this location at a flow rate of 1 ft³/min. The Andersen impactor is a multistage sampler that draws dust-laden air samples through a series of plates containing successively smaller orifices, which increase the velocity of the dust particles as they are transported from one stage to the next. At some stage in the impactor, the velocity of the particle is such that the particle is inertially impacted onto the collection substrate. For a given sampling rate, particles that impact on a particular stage of the impactor correspond to a given particle size range. The submicrometer particles that are not collected on the bottom stage of the impactor are caught in a backup filter. The impactor was operated with a preseparator that prevented particles larger than 10 μ m from entering the filter collection stages of the impactor.

Three isokinetic probes, with inlet diameters of 0.29 in, were evenly spaced across the width of the ductwork and mounted at the intake sampling station (fig. 5). Each probe could be adjusted to three different heights in the ductwork, resulting in a nine-point sampling grid. The impactor was operated for an equivalent time period at each probe location, in a random order to minimize sampling bias.

The sampled air was carried from the isokinetic probes into a trap and then to the impactor. The trap, a can

fitted with inlet and outlet nozzles, was an area of lower air velocity that would induce larger particles, solid or liquid, to drop out of the airstream before being carried to the impactor. The trap was primarily added for the discharge sampling station where water droplets are likely to be encountered. However, to maintain identical sampling conditions at each sampling location, a trap was also used at the intake sampling station.

A real-time aerosol monitor (RAM-1) was also located at the intake sampling station to provide an instantaneous readout of the respirable dust concentration in the intake duct during testing. A stationary isokinetic probe with a 0.076-in-diameter inlet was used with the RAM. All RAM sampling was conducted at one location near the center of the ductwork to obtain a relative check of the dust levels throughout a test.

A discharge sampling station was located 13 ft downstream from the mist eliminator. This sampling station was identical to the intake station except that a RAM sampler was not used.

Provisions to measure the air velocity in the test facility were provided immediately upstream of each sampling station. Three 3/16-in-diameter holes were drilled in the top panel of the duct to allow for insertion of a hot-wire anemometer probe to measure airflow velocity. A center-point velocity measurement was made at each of the three access locations and used to calculate average air velocity.

Airflow for the tests was provided by an axial flow fan rated at approximately 10,000 ft³/min. A regulator door located in the transition piece from the test-unit ductwork to the fan was adjusted to control the amount of air entering the system. After the regulator had been adjusted at the outset of each test, the airflow setting was maintained throughout the test.

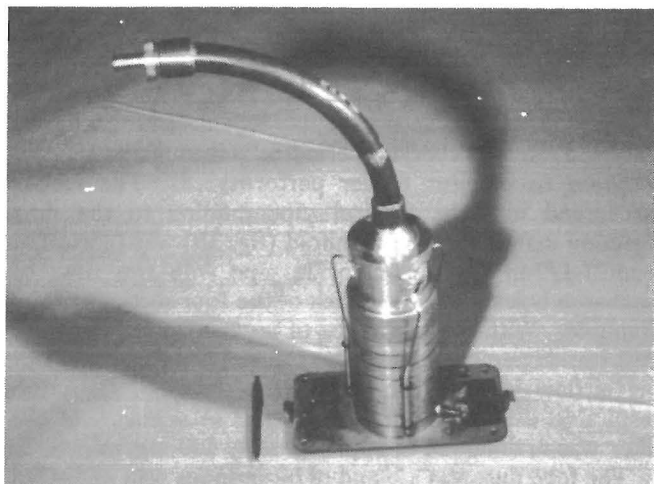


Figure 4.—Andersen eight-stage impactor.

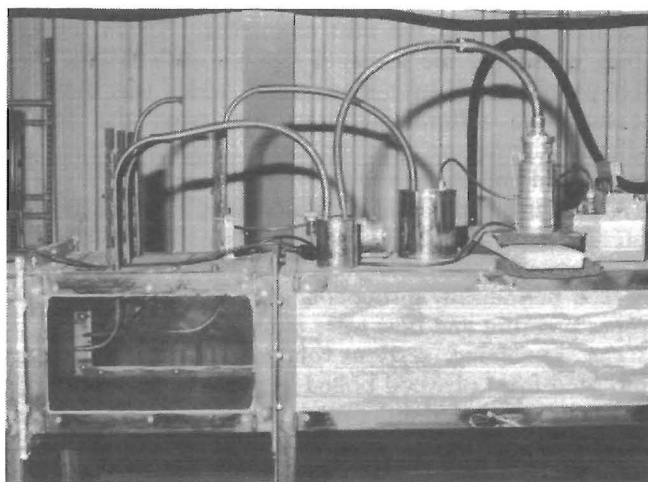


Figure 5.—Intake sampling station.

DUST CONTROL TECHNIQUES

A total of 10 dust control techniques were evaluated to determine their effectiveness. In addition, one test series was conducted with increased quartz levels in the feed dust to determine impact on collection efficiency. A brief description of each test series is provided:

1. *Joy 40-layer filter (J40L).*—The Joy 40-layer filter was the standard filter available from the manufacturer at the outset of the test program. This filter contained 40 layers of stainless steel mesh, fabricated from 0.0035-in-diameter interwoven steel wire and supported by perforated stainless steel plates on both sides (fig. 6). This filter panel simply slides into a channel in the scrubber unit and is ready for use.

2. *Joy 80-layer filter (J80L).*—This filter is identical to the Joy 40-layer filter except that 80 layers of stainless steel mesh are used.

3. *Bondina filter (BOND).*—A synthetic fiber material was substituted for the stainless steel mesh in a panel similar to the Joy filter. A Joy filter panel was disassembled, and the perforated steel plate was used to support the Bondina filter in a new frame (fig. 7). Therefore, the Bondina and Joy filters had equivalent areas of exposed filter material.

4. *Dustrol 10 surfactant (DSTR).*—Dustrol 10 surfactant was added to the spray water at a concentration of 0.1 pct with a metering pump. A pump calibration was conducted to determine the proper pump setting needed to obtain the desired concentration. The Joy 40-layer filter was used in the scrubber during this testing.

5. *Bete P48 atomizing sprays (ATOM).*—Two Bete P48 atomizing sprays were installed in the center of the ductwork upstream of the standard washdown sprays and were operated at 80 psi. These preconditioning sprays were added in hopes of providing additional coal wetting. The testing was conducted with the Joy 40-layer filter in the scrubber.

6. *Fogging sprays (FOGG).*—A set of nine fogging sprays were installed for preconditioning in the ductwork upstream of the standard washdown sprays (fig. 8). These fogging sprays were operated at 700 psi, utilizing approximately 0.1 gpm in total flow. In addition, 10- and 5- μ m filters and water conditioning crystals were installed in the water supply line to the fogging sprays. This water treatment is necessary to reduce the clogging potential of the small-diameter fogging nozzles, which disperse 10- μ m water droplets into the air. The fogging sprays were tested with the Joy 40-layer filter in the scrubber.

7. *Kon-tane filter (KONT).*—The Kon-tane filter was fabricated from a plastic square mesh material, originally designed for scrubbing mists from industrial stacks that have lower air velocities than those encountered in the test facility. Several mesh sizes are available and can be

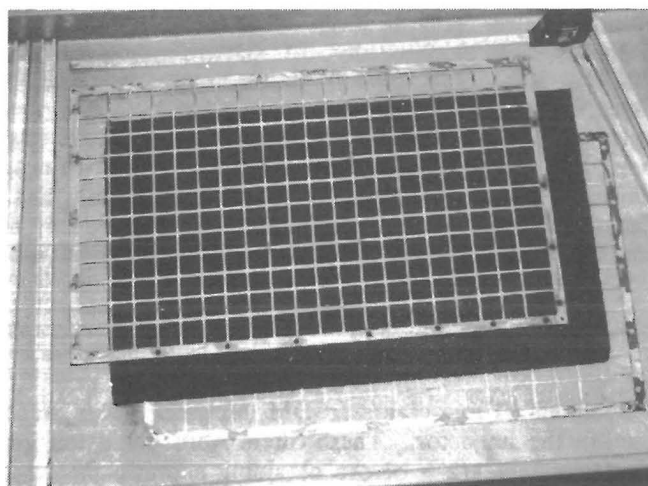


Figure 7.—Components of Bondina filter panel used for testing.

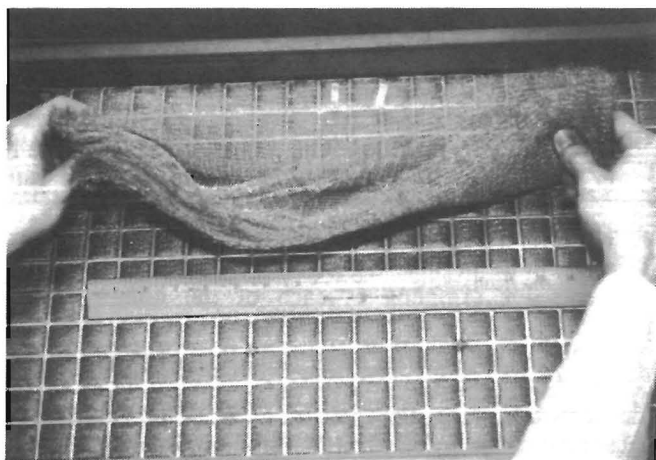


Figure 6.—Joy 40-layer filter panel.

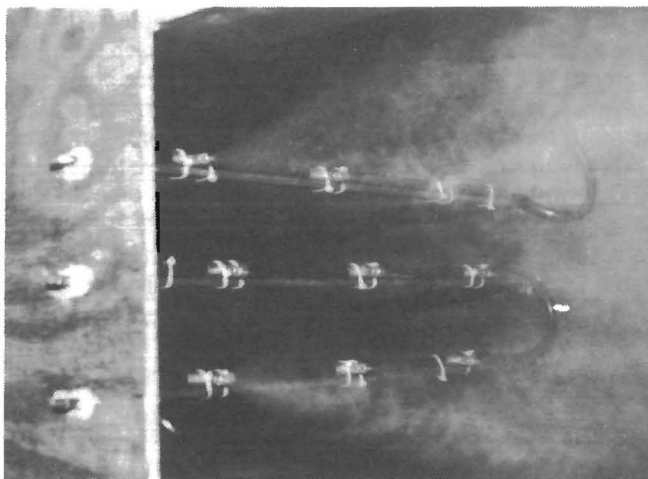


Figure 8.—Fogging sprays operating in system ductwork.

layered to produce the desired density. At the recommendation of the supplier, two coarse-mesh panels, style 37/94, and one medium-mesh panel, style 8/96, were combined for testing. The combined filter was placed adjacent to the mist eliminator in the larger section of the scrubber, where the air velocity would be reduced. However, in this position, the filter was farther from the standard washdown sprays. No other filter was used in the normal scrubber filter location.

8. *Joy 30-layer filter (J30L).*—After the start of the test program, Joy began offering a 30-layer stainless steel mesh filter as the standard filter for their scrubber units. This filter was identical to the 40-layer filter except for the thickness.

9. *Twenty percent quartz in feed (20%Q).*—The Joy 40-layer filter was used in tests conducted with a feed dust mixed to contain 20 pct quartz instead of 10 pct to determine the impact of increased quartz content on filter efficiency.

10. *Exxon Kutwell 40 oil emulsion (OIL).*—Exxon Kutwell 40 oil was used as an additive to the spray water at a concentration of 5 pct to increase coal wetting and collection. The same metering pump used for the Dustrol 10 additive was used to inject the oil into the water supplying the washdown sprays. Oil emulsion was viewed as an additive readily available at most mines, which was less expensive than typical wetting agents. Because of the lower cost associated with the oil, the oil emulsion could be injected at a higher concentration than

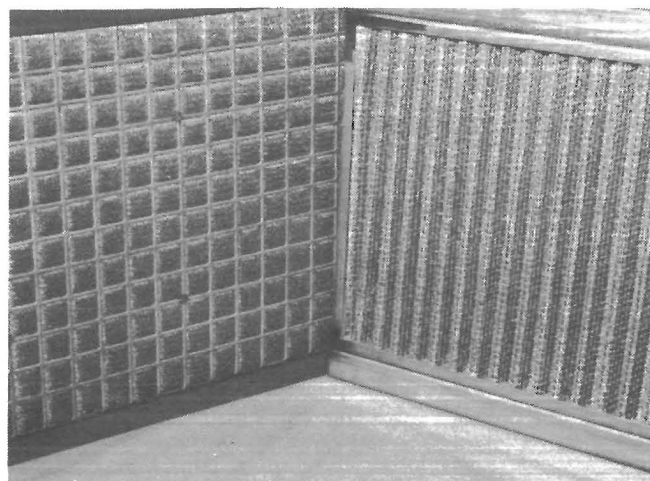


Figure 9.—Comparison of Joy 40-layer flat filter (left) and 30-layer pleated filter (right) panels.

the Dustrol 10 additive without increasing the cost per gallon of spray water.

11. *Joy 30-layer pleated filter (PLTD).*—A Joy 30-layer stainless steel mesh filter, fabricated in a pleated design (fig. 9) to increase surface area of the filter, was used. This filter was tested after modifying the filter holder in the scrubber to accept the wider pleated panel.

TEST PROCEDURES AND CONDITIONS

Gelman 81-mm-diameter DM Metrical filters were used in the impactor. These filters were evacuated for approximately 1/2 h before obtaining a preweight on a Mettler model H54AR balance. After weighing, the filters were loaded into the impactors in preparation for testing.

After preparing the test facility for the test condition to be evaluated and positioning the dust samplers, the fan was started and the airflow was measured at each sampling station. The intake and discharge airflows were compared since a large deviation would indicate a leak, most likely at the filter door or the mist eliminator door. However, throughout the test series, only minor deviations were observed, indicating that the seals were maintained.

Adjustments to the regulator were made as needed to bring the airflow velocity at the intake station to 2,200 fpm (± 100 fpm). Given the internal area of the ductwork, this air velocity represents a volumetric airflow of approximately 5,000 ft³/min.

Waterflow to the filter sprays was then started, and the pressure regulator was adjusted to obtain the desired pressure of 80 psi. At this pressure, the average water usage of the sprays was approximately 7 gpm.

Once airflow and waterflow had been established, the dust feed was started. The RAM sampler was used to determine when the dust levels had stabilized before beginning to sample with the impactors.

The intake impactor was exposed to a dust cloud of roughly 100 mg/m³ and could only be operated for a total sampling time of approximately 10 min without overloading the impactor's upper stage filters. Given this restriction, the intake impactor was operated for 65 s at each of the nine available sampling points. The 65-s-sampling periods were conducted at equal intervals starting every 14 min throughout the tests.

The discharge impactor was exposed to substantially lower dust levels. Therefore, it was necessary to operate the discharge impactor for approximately 126 min to collect sufficient quantities of dust on each impactor filter. This sampling period was divided into nine equal time segments for sampling at each of the nine sampling locations.

After completion of each test, the filter panel was removed and washed with water. The inside walls of the ductwork were also sprayed with water to remove accumulated dust. The test facility and filter panel were

allowed to dry overnight so that similar conditions were present at the start of each test.

The impactor filters were reweighed after being placed in a vacuum chamber for at least 30 min, allowing

accumulated moisture to be removed. The filters from stages 3 to 6 of the intake and discharge impactors were then sent to an independent laboratory for quartz analysis using the procedure recommended by MSHA.⁶

TEST RESULTS

The initial analysis of the impactor samples was to determine the dust collection efficiency for the respirable fraction of the coal-quartz feed blend. The total weight collected on all filters from each impactor was used to calculate intake and discharge respirable dust concentrations. The difference between these concentrations was then used to calculate the overall collection efficiency for each test (see table A-2). The individual test averages for each test condition were combined for an overall test condition average and are summarized in table 1. Figure 10 illustrates the relative effectiveness of each test condition. The most effective control was obtained with the Joy 80-layer filter, which resulted in a 99.0 pct dust reduction. Figure 10 also shows the Bondina filter, Dustrol 10 surfactant, and oil emulsion to be over 97 pct effective in removing minus 10- μ m particles. Only the Joy 30-layer filter and the Kon-tane filter material resulted in dust reductions less than 95 pct.

Table 1.—Average dust collection efficiencies for each test condition, percent

Test condition	Feed (-10 μ m)	Coal (0.7-4.7 μ m)	Quartz (0.7-4.7 μ m)
Joy 40-layer filter (J40L) ..	96.2	94.6	90.2
Joy 80-layer filter (J80L) ..	99.0	98.3	98.3
Bondina filter (BOND)	97.8	96.9	94.9
Dustrol 10 surfactant (DSTR)	97.3	95.8	91.3
Bete P48 atomizing sprays (ATOM)	96.3	93.4	90.2
Fogging sprays (FOGG) ..	96.4	95.0	94.7
Kon-tane filter (KONT) ...	91.7	87.8	91.3
Joy 30-layer filter (J30L) ..	93.2	90.7	91.3
20 pct quartz in feed (20%Q)	96.3	95.0	90.2
Exxon Kutwell 40 oil emulsion (OIL)	97.2	96.0	92.2
Joy 30-layer pleated filter (PLTD)	95.8	94.3	91.6

In addition to overall dust collection efficiency, the dust concentration for each stage of the impactor was calculated and used to determine a collection efficiency for each size range of the impactor. An average collection efficiency based on size range was calculated for each test condition, and these values are summarized in table 2. The data indicate that above 5 μ m, the relative differences in collection efficiency for the various test conditions are generally not very significant and show that very high collection efficiencies were realized. However, as the

particle size decreases, the collection efficiency also decreases, and the differences between test conditions become more significant. Also, the primary focus of this research effort was directed toward quartz dust collection, and previous research⁷ has shown that during normal mining operations, a higher percentage of quartz is present in the finer size range. As a result, the filters from stages 3 to 6 of the impactors (0.7- to 4.7- μ m particles) were of greater interest and were sent to an independent laboratory for quartz analysis.

The ideal sample weight range for quartz analysis as described in MSHA Standard Method P7 is 0.5 to 2.0 mg. Because of the low dust weights obtained on some filters from stage 6 of the impactor, the filters from two or more tests for a given test condition had to be combined for analysis. In addition, two sets of impactor filters were used with the intake impactor, starting with test 13, in an

⁶Goldberg, S. A., T. F. Tomb, P. M. Kacmar, J. J. Baber, Jr., and M. J. Busa. MSHA's Procedure for Determining Quartz Content of Respirable Coal Mine Dust. MSHA IR 1152, 1984, 13 pp.

⁷Ramani, R. V., J. M. Mutmansky, R. Bhaskar, and J. Qin. Fundamental Studies on the Relationship Between Quartz Levels in the Host Material and the Respirable Dust Generated During Mining, Volume 1: Experiments, Results and Analyses (contract H0358031, PA State Univ.). BuMines OFR 36-88, 1987, 179 pp.; NTIS PB 88-214325.

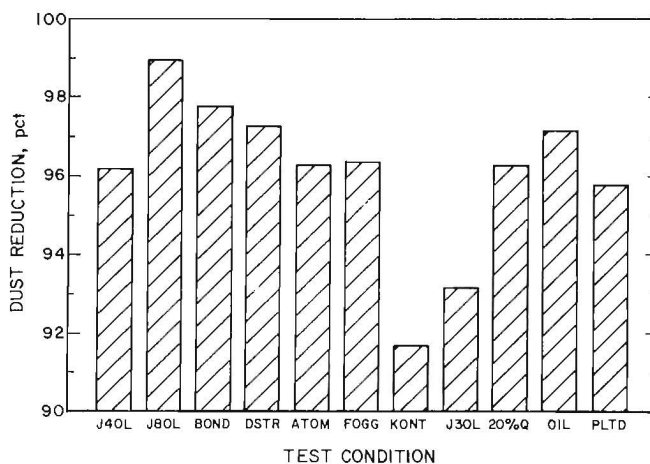


Figure 10.—Feed dust collection efficiencies for minus 10- μ m particles. (See table 1.)

effort to collect more dust for quartz analysis, primarily for stage 6 samples. The time interval between 65-s-sampling periods was reduced to 7 min, and the filters in the intake impactor were replaced after half of the scrubber test had been completed. These measures resulted in approximately 95 pct of the samples meeting the minimum ideal sample weight of 0.5 mg. Analyses of samples containing depositions above 2 mg were run on one-fifth aliquot.

Table 2.—Average impactor collection efficiencies for each test condition¹ by stage and impactor size classification, percent

Stage	Size, μm	J40L	J80L	BOND	DSTR	ATOM	FOGG
0 ...	9.0-10.0	99.5	99.8	99.6	99.8	99.5	99.5
1 ...	5.8- 9.0	99.3	99.7	99.7	99.7	99.3	99.2
2 ...	4.7- 5.8	99.2	99.4	99.7	99.4	99.1	98.7
3 ...	3.3- 4.7	97.8	99.2	99.4	99.0	98.0	98.2
4 ...	2.1- 3.3	95.0	98.4	97.7	96.1	95.1	95.4
5 ...	1.1- 2.1	87.7	95.1	90.9	91.5	88.9	89.2
6 ...	.7- 1.1	22.6	78.5	52.7	70.6	61.2	57.4
	Size, μm	KONT	J30L	20%Q	OIL	PLTD	
0 ...	9.0-10.0	98.8	98.6	99.4	99.8	99.7	
1 ...	5.8- 9.0	98.8	98.2	99.2	99.6	99.7	
2 ...	4.7- 5.8	98.1	97.5	99.0	99.5	99.4	
3 ...	3.3- 4.7	96.4	95.9	98.1	99.0	98.8	
4 ...	2.1- 3.3	88.1	91.4	95.4	96.6	95.9	
5 ...	1.1- 2.1	72.0	81.1	87.6	91.3	85.9	
6 ...	.7- 1.1	3.4	35.2	23.0	40.5	39.5	

¹See table 1.

NOTE.—No data available for stages 7 (0.4- to 0.7- μm size) and 8 (0.0- to 0.4- μm size) because of insufficient weights for valid analysis.

The quartz weights obtained for the intake filters from stages 3 to 6 were combined, and using the sampling time, an intake quartz concentration was calculated for each test. Similarly, a discharge concentration was obtained. The intake and discharge concentrations were used to calculate the percentage reduction in quartz dust for each test (see appendix A). Table 1 contains the average reduction calculated for each test condition. Figure 11 graphically displays the data and shows that the Joy 80-layer filter is again the most effective (98.3 pct), with the Bondina filter and the fogging sprays the only other two conditions having quartz reductions greater than 94 pct.

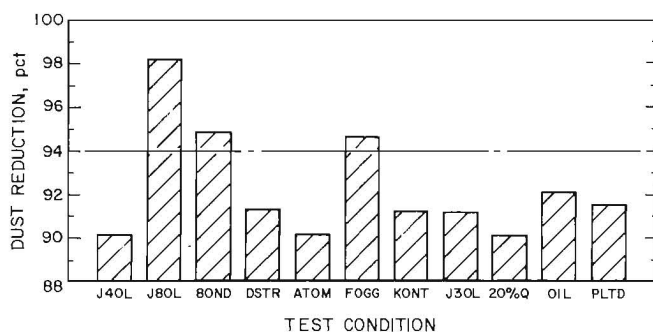


Figure 11.—Quartz dust collection efficiencies for 0.7- to 4.7- μm particles. (See table 1.)

A comparison between the average percentage reduction for quartz for the Joy 40-layer filter and each of the other 10 test conditions was made using analysis of variance (ANOVA). As expected, only the Joy 80-layer filter, Bondina filter, and fogging sprays showed statistically significant differences at a 95-pct confidence level in average percentage reduction for quartz. Summary of the ANOVA data are provided in table 3.

Table 3.—ANOVA data for comparison to standard filter

Test condition ¹	Identification (i)	Null hypothesis ² (H ₀)	Variance ratio (F*)	F(0.95; 1, n _T -2)	Decision ³
J40L ...	1	NAP	NAP	NAP	NAP
J80L ...	2	$\mu_1 = \mu_2$	16.62	5.99	R
BOND ...	3	$\mu_1 = \mu_3$	5.69	5.59	R
DSTR ...	4	$\mu_1 = \mu_4$	.33	5.59	A
ATOM ...	5	$\mu_1 = \mu_5$	.00	5.59	A
FOGG ...	6	$\mu_1 = \mu_6$	6.31	5.59	R
KONT ...	7	$\mu_1 = \mu_7$	.55	5.99	A
J30L ...	8	$\mu_1 = \mu_8$	.05	5.59	A
20%Q ...	9	$\mu_1 = \mu_9$	.04	5.59	A
OIL ...	10	$\mu_1 = \mu_{10}$	.43	5.59	A
PLTD ...	11	$\mu_1 = \mu_{11}$	.41	5.59	A

NAP Not applicable.

¹See table 1.

²H₀ (null): $\mu_1 = \mu_i$; H_a (alternative): $\mu_1 \neq \mu_i$.

³Decision rule: If $F^* < F(1-\alpha; r-1, n_{T-r})$ accept H₀ (A); if $F^* > F(1-\alpha; r-1, n_{T-r})$ reject H₀ (R). (A = accept; R = reject.)

One of the goals of this program was to determine how effective the flooded-bed scrubber was for removing quartz dust. Consequently, a comparison between the quartz removal efficiency and coal removal efficiency was examined. Since the quartz weight for each impactor filter was determined and the total dust weight of the filter was known, the difference between these two weights could be attributed to the coal portion of the original feed dust. As a result, the average coal dust concentrations for the intake and discharge filters for stages 3 to 6 of the impactor were calculated (table A-4) and used to calculate an average percentage reduction in coal dust for each test condition (table 1, fig. 12). As shown earlier, only 3 of the 11 test conditions exhibited quartz reductions greater than 94 pct, while an examination of the data presented in figure 12 shows that 8 of the 11 had coal reductions greater than 94 pct. These results indicate that a difference in collection efficiency does exist between coal and quartz.

The data in figures 11 and 12 are combined in figure 13 to simplify the comparison between the coal and quartz collection efficiencies for each test condition. For all but two test conditions, the coal collection efficiency is greater than the quartz efficiency. It is felt that test anomalies account for the higher quartz collection efficiencies in these two cases, as discussed below.

In general, particle density, particle size distribution, and wetability may contribute to the difference between collection efficiencies for coal and quartz. Future research beyond the scope of this program is needed to make more definitive conclusions.

Although the differences between quartz and coal collection do not appear great, these small differences can have a significant impact on discharge dust composition and resulting dust standards. At present, federal regulations maintain that the maximum 8-h worker exposure level is 2 mg/m^3 , with 5 pct or less being quartz. If the sample contains more than 5 pct quartz, the maximum limit of 2 mg/m^3 is reduced based on the formula $10/(\text{pct quartz}) = \text{new maximum, mg/m}^3$. The following example illustrates:

Assume 100 mg of dust with 5 pct being quartz:

Joy filter	Scrubber intake		Collection efficiency, pct	Scrubber discharge	
	Dust, mg	Dust, pct		Dust, mg	Dust, pct
40-layer:					
Coal	95.0	95.0	94.6	5.130	91.3
Quartz	5.0	5.0	90.2	.490	8.7
80-layer:					
Coal	95.0	95.0	98.3	1.615	95.0
Quartz	5.0	5.0	98.3	.085	5.0

With the 40-layer filter, the scrubber discharge contained a higher percentage of quartz than the intake dust because of the difference in collection efficiencies for coal and quartz. The resulting higher quartz concentration could contribute to a more stringent dust standard for personnel downwind of the continuous miner, as low as 1.15 mg/m^3 (10/8.7 pct quartz) if downwind of the miner for an entire shift. Also, note the difference between the amount of dust that passes through the filters and into the discharge air. For coal, the 40-layer filter allows 5.13 mg to pass, while only 1.62 mg penetrates the 80-layer filter, a ratio higher than 3 to 1. The difference is even greater for quartz, as over 5 times more quartz passes through the 40-layer filter.

Therefore, the relative collection efficiencies between coal and quartz, as well as the actual collection efficiencies, become important in determining compliance. As such, table 4 contains the resulting dust standard calculated for each test condition, assuming a dust cloud of 20 mg/m^3 containing 5 pct quartz enters the scrubber. The difference between the resulting dust standard and the total discharge dust concentration was calculated and labeled the compliance margin. Larger compliance margins indicate favorable dust control, while negative margins indicate out-of-compliance conditions. Figure 14 shows the compliance margins for each test condition. The Joy 80-layer filter, fogging sprays, and Bondina filter result in the best dust control and provide the maximum margin for compliance when scrubber discharge dust concentrations are considered. Even though other test conditions may appear more desirable since a more stringent standard would not result, the increase in the discharge dust levels with these test conditions makes them less effective overall and more likely to contribute to an out-of-compliance condition.

In addition to dust levels, other operational considerations must be taken into account before selecting the

appropriate dust control technique. Table 5 contains a summary of the operating conditions for the tests. In general, the conditions were quite consistent for a given test condition, as well as from one test series to the next.

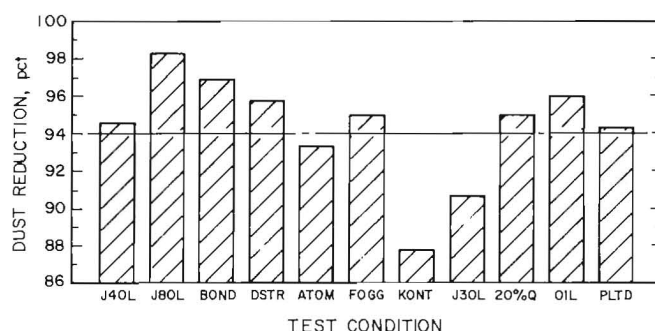


Figure 12.—Coal dust collection efficiencies for 0.7- to 4.7- μm particles. (See table 1.)

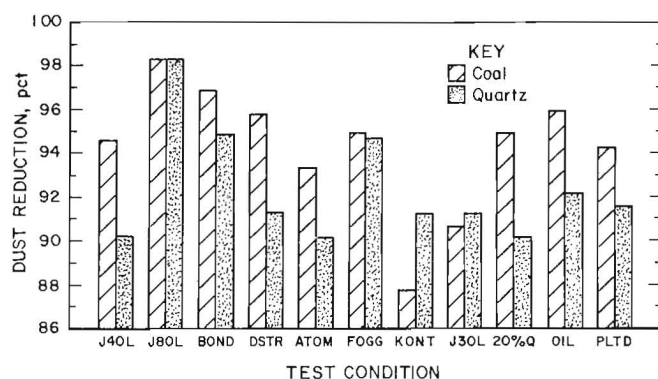


Figure 13.—Comparison of coal and quartz dust collection efficiencies for 0.7- to 4.7- μm particles. (See table 1.)

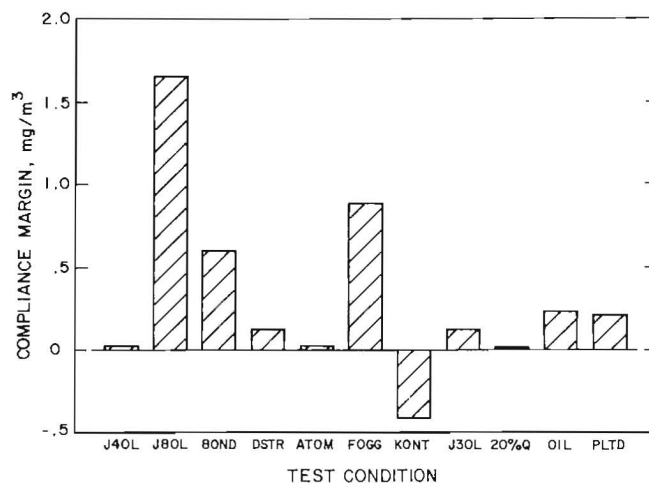


Figure 14.—Calculated compliance margins for each test condition. (See table 1.)

Table 4.—Calculation of compliance margin for each test condition

[Assume 20 mg/m³ dust cloud with 5 pct quartz entering scrubber (19 mg/m³ coal and 1 mg/m³ quartz)]

Test condition ¹	Average collection efficiency		Discharge concentration, mg/m ³			Quartz in scrubber discharge, pct	Resulting dust standard, mg/m ³	Compliance margin, mg/m ³
	Coal	Quartz	Coal	Quartz	Total			
J40L	94.6	90.2	1.026	0.098	1.12	8.72	1.15	0.03
J80L	98.3	98.3	.323	.017	.34	5.00	2.00	1.66
BOND	96.9	94.9	.589	.051	.64	7.97	1.25	.61
DSTR	95.8	91.3	.798	.087	.89	9.83	1.02	.13
ATOM	93.4	90.2	1.254	.098	1.35	7.25	1.38	.03
FOGG	95.0	94.7	.950	.053	1.00	5.28	1.89	.89
KONT	87.8	91.3	2.318	.088	2.41	3.66	2.00	-.41
J30L	90.7	91.3	1.786	.087	1.87	4.64	2.00	.13
20%Q	95.0	90.2	.950	.098	1.05	9.35	1.07	.02
OIL	96.0	92.2	.779	.078	.86	9.10	1.10	.24
PLTD	94.3	91.6	1.083	.084	1.17	7.20	1.39	.22

¹See table 1.

Table 5.—Summary of average operating conditions

Test condition ¹	Waterflow, gpm	Water pressure, psi	Air velocity, ft ³ /min	Pressure differential across scrubber filter, in H ₂ O		
				Initial	Final	Gain
J40L	6.7	84	2,230	4.1	4.2	0.1
J80L	6.5	86	2,183	8.0	8.2	.2
BOND	7.0	82	2,225	4.3	4.5	.2
DSTR	6.9	81	2,244	4.1	4.3	.2
ATOM	7.6	81	2,250	3.8	4.0	.2
FOGG	7.0	81	2,263	4.4	4.6	.2
KONT	6.9	82	2,242	5.6	6.3	.7
J30L	6.9	82	2,250	2.7	2.8	.1
20%Q	6.9	82	2,225	4.0	4.1	.1
OIL	6.7	82	2,250	4.4	4.7	.3
PLTD	6.8	81	2,269	2.9	2.9	.0

¹See table 1.

CONCLUSIONS

Laboratory tests have shown that collection efficiencies greater than 90 pct for both coal and quartz dust could be achieved for most of the techniques evaluated. However, a difference in collection efficiency between quartz and coal was found to exist for most of the conditions tested. Although these differences were relatively small, it was shown that an undesirable impact on discharge dust composition resulted. Consequently, the absolute quartz collection efficiency and the quartz efficiency relative to the coal collection efficiency had to be examined to determine the true effectiveness of each control technique. A brief comment concerning the results for each test condition is provided:

1. *Joy 40-layer filter.*—A difference between the collection efficiencies for coal (94.6 pct) and quartz (90.2 pct) of nearly 4.5 pct was observed. The initial pressure drop across the filter was 4.1 in of water, with an increase of 0.1 in after testing. This control technique was considered the baseline condition, and these results were used for comparing the relative effectiveness of the other test conditions.

2. *Joy 80-layer filter.*—This test condition resulted in the highest collection efficiency for both coal and quartz and was the only test condition that had equivalent collection efficiencies for both types of dust (98.3 pct). The doubling of the filter density resulted in an average initial pressure drop across the filter of 8.0 in of water, nearly twice as high as the Joy 40-layer filter.

3. *Bondina filter.*—The Bondina filter was tested as an alternate filter material. This material had similar pressure drop characteristics across the filter as the Joy 40-layer filter, but improved the dust collection efficiency to 96.9 pct for coal and 94.9 pct for quartz.

4. *Dustrol 10 surfactant.*—This additive to the washdown spray water was used in conjunction with the Joy 40-layer filter panel. The addition of the Dustrol 10 surfactant did not significantly alter the dust control (1.2 pct increase for coal and 1.1 pct increase for quartz) or pressure drop conditions found for the baseline conditions.

5. *Bete P48 atomizing sprays.*—These preconditioning sprays did not improve coal or quartz dust control, yet increased water consumption.

6. *Fogging sprays.*—High-pressure, preconditioning sprays produced finer water droplets than the atomizing sprays and only utilized 0.1 gpm. These fogging sprays resulted in a coal dust collection efficiency (95.0 pct), slightly higher than the Joy 40-layer filter, but showed a more substantial improvement of 94.7 pct for quartz.

7. *Kon-tane filter.*—The Kon-tane filter was the only test condition that had a collection efficiency for coal (87.8 pct) that was less than 90 pct. The filter material was designed for lower air velocity applications and was not adaptable to the higher velocity found in the test unit. The filter did show a higher reduction for quartz than for coal. However, the filter was positioned adjacent to the mist eliminator so that the filter was exposed to lower air velocities and was not completely washed by the water sprays, which could substantially alter the collection characteristics of the filter. Also, the filter did exhibit an average increase in pressure drop over each test period of 0.7 in of water, which is more than twice as high as any other test condition.

8. *Joy 30-layer filter.*—The Joy 30-layer filter was designed to improve pressure drop across the filter and succeeded by reducing the initial pressure drop to 2.7 in of water, nearly 1.5 in less than the 40-layer filter. Coal collection efficiency was 90.6 pct, 4 pct less than the 40-layer filter, but the quartz collection efficiency increased by 1.1 pct. This was a surprising contradiction and the only tests conducted with a Joy filter that resulted in a higher quartz collection efficiency than that for coal. Review of the data obtained with the Joy pleated panel, also containing 30-layers of stainless steel, resulted in typical collection efficiencies, ruling out the 30-layer design as a contributor to this inconsistency. These factors lead to questions concerning the validity of the data for the

30-layer panel. The test data and filter data from these tests were reviewed for possible explanations. The only irregularity found was for the quartz dust data. For the intake samples, the quartz weights were very low (less than 0.2 mg) and the quartz weights in the discharge samples were much more erratic than those for other test conditions. No identifiable anomalies for the coal collection efficiencies were found. However, the collection efficiency data for the 30-layer filter should be considered suspect and cannot be utilized with confidence.

9. *Twenty percent quartz in feed.*—The increase in the quartz content had no significant impact on the collection efficiency of the Joy 40-layer filter. The quartz collection efficiency was identical to the base condition, while the coal collection efficiency differed by only 0.4 pct.

10. *Exxon Kutwell 40 oil emulsion.*—The use of oil emulsion in the spray water showed some improvement in the coal (1.4 pct) and quartz (2.0 pct) collection efficiency, but not enough to show a statistically significant difference. Also, the oil emulsion appeared to adhere to the filter panel and could not be rinsed off with water after testing. After completion of the first two tests, the panel was cleaned with alcohol for the last two tests. The use of the oil emulsion increased the average initial pressure drop to 4.4 in of water, resulting in the highest average pressure drop increase over the test period, 0.3 in of water except for the Kon-tane material.

11. *Joy 30-layer pleated filter.*—The Joy pleated panel, with only 30 layers of stainless steel mesh, had a reduced initial pressure drop of 2.9 in of water. A coal collection efficiency of 94.3 pct was obtained, which is similar to the 40-layer filter. A slight increase in quartz collection to 91.6 pct was observed.

RECOMMENDATIONS

The Joy 80-layer filter resulted in the most desirable dust control for all of the comparisons made and would be very easy to implement underground. However, the 80-layer panel is obviously twice as dense as the standard 40-layer panel, which resulted in an average pressure drop of 8.0 in of water across the filter when clean. This pressure drop is too high for the scrubber fans currently being used on continuous mining machines. In most cases, fan stall would occur shortly after the fan was started. Thus, the 80-layer panel is the most desirable option tested from a laboratory viewpoint, but is not a practical option for mining companies without implementing an improved fan.

The next best option from a dust control standpoint is the fogging spray system. These sprays could be added to current scrubber units, but would require the installation of a high-pressure pump and a stringent filtration system to minimize blockage of the small spray orifice in each nozzle. Even though the filtration system supplied by the manufacturer was utilized for the laboratory testing, some nozzle blockage was encountered that necessitated cleaning of the nozzles. Nozzle cleaning underground would

require modifications to the scrubber ductwork to permit ready access to the nozzles. Consequently, implementation of the fogging sprays in the underground environment would require substantial system modification and high maintenance to keep the spray nozzles in operation.

The Bondina filter material appears to be the control technique that offers the greatest dust control in conjunction with ease and success of application. Although the Bondina filter does not appear as durable as stainless steel mesh, it could be replaced more cheaply, particularly if a frame was fabricated that would allow changing of the filter material while continuing to use the same frame and perforated plate.

Therefore, the Bondina material is the option tested during this program that combines the highest dust collection with the greatest likelihood of successful application in the underground mining environment at this time.

If pressure drop across the filter and fan stall problems are a concern, the test results indicate that the Joy 30-layer pleated filter panel offers a reduced pressure drop, yet has similar dust collection characteristics as the 40-layer panel.

APPENDIX.—SAMPLING DATA

Table A-1.—Subsieve particle size analysis for coal and quartz dust components

Size, μm	Cumulative vol pct greater than size		Size range, μm	Differential vol pct in stated size range	
	Coal	Quartz		Coal	Quartz
2.00	99.2	99.2	2.00-2.52	2.6	5.0
2.52	96.7	94.4	2.52-3.17	3.3	6.4
3.17	93.4	88.3	3.17-4.00	4.0	7.5
4.00	89.4	81.0	4.00-5.04	5.2	9.5
5.04	84.2	71.8	5.04-6.35	7.1	12.1
6.35	77.1	60.0	6.35-8.00	9.1	14.3
8.00	68.1	46.0	8.00-10.08	11.7	17.2
10.08	56.4	28.9	10.08-12.7	14.0	15.5
12.7	42.4	13.6	12.7-16.0	15.3	9.0
16.0	27.1	4.5	16.0-20.2	13.2	3.0
20.2	13.8	1.5	20.2-25.4	9.0	1.5
25.4	4.7	0	25.4-32.0	2.7	0
32.0	1.9	0	32.0-40.3	1.0	0
40.3	.7	0	40.3-50.8	.7	0

Table A-2.—Feed dust collection efficiencies for minus 10- μm particles

Test condition ¹	Test	Dust concentration, mg/m ³		Dust reduction, pct		Test condition ¹	Test	Dust concentration, mg/m ³		Dust reduction, pct		
		Intake	Discharge	Test result	Average			Intake	Discharge	Test result	Average	
J40L ...	1	95.2	2.9	97.0	96.2	KONT ..	30	89.6	6.1	93.2	91.7	
	3	137.8	4.9	96.4			33	77.3	6.9	91.1		
	5	123.6	4.9	96.1			37	94.5	8.6	90.9		
	11	99.9	4.4	95.6		J30L ...	31	63.4	4.8	92.5	93.2	
	12	89.3	3.5	96.1			34	54.0	3.2	94.0		
J80L ...	2	154.0	.7	99.5	99.0		36	80.5	6.0	92.6		
	4	135.3	2.1	98.5			38	87.7	5.6	93.6		
	7	173.5	1.8	98.9	20%Q ..	39	85.8	3.6	95.8	96.3		
	8	142.4	1.2	99.2		40	84.8	2.9	96.5			
BOND ..	13	110.4	2.1	98.1		97.8		41	77.2		2.7	96.6
	14	115.6	1.8	98.4				42	81.9		2.9	96.5
	15	99.2	1.8	98.2	OIL	43	81.3	2.1	97.5	97.2		
	16	121.1	4.3	96.5		44	81.9	2.6	96.8			
DSTR ...	18	113.7	2.8	97.5		97.3		45	67.7		1.7	97.4
	19	111.5	3.3	97.1				46	89.5		2.6	97.1
	20	109.3	2.9	97.3	PLTD ...	47	93.2	3.5	96.3	95.8		
	21	125.6	3.5	97.2		48	102.1	4.5	95.6			
ATOM ..	22	146.7	5.2	96.4		96.3		49	93.2		4.1	95.6
	23	115.5	4.4	96.2				50	92.1		3.8	95.9
	24	133.9	5.4	95.9								
	25	139.5	4.5	96.8								
FOGG ..	26	110.7	4.0	96.4	96.4							
	27	110.9	4.3	96.2								
	28	118.3	4.4	96.3								
	29	87.0	2.9	96.7								

¹See table 1.

**Table A-3.—Quartz dust collection efficiencies
for 0.7- to 4.7- μ m particles**

Test condition ¹	Test	Dust concentration, mg/m ³		Dust reduction, pct	
		Intake	Discharge	Test result	Average
J40L ...	1	3.88	0.31	92.0	90.2
	3	3.12	.37	88.1	
	5	5.15	.34	93.4	
	11	4.16	.61	85.3	
	12	4.22	.33	92.2	
J80L ...	4	6.74	.13	98.1	98.3
	7	10.02	.13	98.7	
	8	6.08	.11	98.2	
BOND ..	13	3.92	.15	96.2	94.9
	14	5.95	.16	97.3	
	15	3.68	.28	92.4	
	16	4.72	.30	93.6	
DSTR ...	18	2.18	.16	92.7	91.3
	19	2.12	.19	91.0	
	20	2.18	.18	91.7	
	21	2.19	.22	90.0	
ATOM ..	22	2.12	.10	95.3	90.2
	23	1.50	.24	84.0	
	24	1.99	.28	85.9	
	25	3.52	.15	95.7	
FOGG ..	26	1.31	.07	94.7	94.7
	27	1.30	.06	95.4	
	28	1.29	.05	96.1	
	29	1.36	.10	92.6	
KONT ..	30	2.75	.10	96.4	91.3
	33	.77	.10	87.0	
	37	1.14	.11	90.4	
J30L ...	31	.36	.01	97.2	91.3
	34	.57	.06	89.5	
	36	.51	.02	96.1	
	38	.40	.07	82.5	
20%Q ..	39	3.63	.26	92.8	90.2
	40	3.44	.27	92.2	
	41	2.31	.28	87.9	
	42	2.50	.30	88.0	
OIL	43	1.23	.12	90.2	92.2
	44	1.45	.07	95.2	
	45	.97	.14	85.6	
	46	1.27	.03	97.6	
PLTD ...	47	.51	.07	86.3	91.6
	48	.63	.04	93.7	
	49	.79	.06	92.4	
	50	.83	.05	94.0	

¹See table 1.

**Table A-4.—Coal dust collection efficiencies
for 0.7- to 4.7- μ m particles**

Test condition ¹	Test	Dust concentration, mg/m ³		Dust reduction, pct	
		Intake	Discharge	Test result	Average
J40L ...	1	53.7	2.4	95.5	94.6
	3	82.7	4.0	95.1	
	5	67.2	3.6	94.7	
	11	54.0	3.2	94.0	
	12	47.9	3.0	93.7	
J80L ...	4	72.9	1.7	97.7	98.3
	7	92.8	1.4	98.5	
	8	75.3	.9	98.8	
BOND ..	13	61.2	1.9	96.9	96.9
	14	64.0	1.5	97.6	
	15	52.5	1.4	97.3	
	16	68.4	2.9	95.8	
DSTR ...	18	63.4	2.4	96.3	95.8
	19	64.8	2.4	96.3	
	20	51.3	2.2	95.8	
	21	51.6	2.7	94.7	
ATOM ..	22	74.9	4.4	94.1	93.4
	23	50.8	3.6	93.0	
	24	57.2	3.9	93.1	
	25	59.9	3.9	93.5	
FOGG ..	26	69.2	3.3	95.3	95.0
	27	58.8	3.7	93.7	
	28	64.8	3.3	94.9	
	29	56.0	2.2	96.1	
KONT ..	30	54.1	5.2	90.4	87.8
	33	43.4	6.0	86.3	
	37	54.8	7.3	86.7	
J30L ...	31	39.5	3.6	91.0	90.7
	34	31.4	2.7	91.6	
	36	47.4	4.9	89.6	
	38	51.7	5.0	90.4	
20%Q ..	39	42.6	2.7	93.6	95.0
	40	45.9	2.3	95.0	
	41	45.9	2.0	95.7	
	42	47.1	2.1	95.5	
OIL	43	48.4	1.7	96.5	96.0
	44	46.6	2.3	95.2	
	45	43.5	1.7	96.2	
	46	52.5	2.1	96.0	
PLTD ...	47	56.9	3.1	94.6	94.3
	48	63.9	3.7	94.2	
	49	58.1	3.6	93.8	
	50	58.7	3.2	94.5	

¹See table 1.

Table A-5.—Summary of operating conditions for individual tests

Test condition ¹	Test	Waterflow, gpm	Water pressure, psi	Air velocity, ft ³ /min	Pressure differential across scrubber filter, in H ₂ O		
					Initial	Final	Increase
J40L ...	1	6.5	85	2,200	3.9	4.0	0.1
	3	6.5	85	2,250	3.8	4.0	.2
	5	6.5	85	2,200	4.4	4.6	.2
	11	7.0	82	2,250	4.2	4.3	.1
	12	7.0	82	2,250	4.1	4.2	.1
Average		6.7	84	2,230	4.1	4.2	.1
J80L ...	4	6.5	87	2,200	8.2	8.4	.2
	7	6.5	85	2,150	7.5	7.8	.3
	8	6.5	85	2,200	8.2	8.3	.1
Average		6.5	86	2,183	8.0	8.2	.2
BOND ..	13	7.0	82	2,200	4.3	4.6	.3
	14	7.0	82	2,200	4.3	4.5	.2
	15	7.0	82	2,250	4.4	4.6	.2
	16	7.0	82	2,250	4.3	4.5	.2
Average		7.0	82	2,225	4.3	4.6	.2
DSTR ...	18	6.9	81	2,250	4.1	4.3	.2
	19	6.9	81	2,250	4.2	4.3	.1
	20	6.8	81	2,250	4.1	4.3	.2
	21	6.9	81	2,225	4.1	4.3	.2
Average		6.9	81	2,244	4.1	4.3	.2
ATOM ...	22	7.4	81	2,250	3.8	4.0	.2
	23	7.9	81	2,250	3.9	4.1	.2
	24	7.4	80	2,250	4.0	4.2	.2
	25	7.4	80	2,250	3.6	3.8	.2
Average		7.6	81	2,250	3.8	4.0	.2
FOGG ...	26	6.6	80	2,250	4.4	4.6	.2
	27	6.9	80	2,300	4.5	4.7	.2
	28	7.0	82	2,250	4.5	4.7	.2
	29	7.0	82	2,250	4.2	4.4	.2
Average		6.9	81	2,263	4.4	4.6	.2
KONT ...	30	6.9	82	2,250	² 6.0	² 6.9	.9
	33	6.9	82	2,225	5.5	6.0	.5
	37	7.0	82	2,250	5.2	6.1	.9
Average		6.9	82	2,242	5.6	6.3	.8
J30L ...	31	6.8	82	2,250	2.6	2.7	.1
	34	6.9	82	2,250	2.7	2.7	.0
	36	6.8	82	2,250	2.8	2.8	.0
	38	6.9	82	2,250	2.8	2.8	.0
Average		6.9	82	2,250	2.7	2.8	.0
20%Q ...	39	6.9	82	2,225	3.9	4.0	.1
	40	6.9	82	2,225	3.9	3.9	.0
	41	6.9	82	2,225	3.9	4.0	.1
	42	6.9	82	2,225	4.2	4.3	.1
Average		6.9	82	2,225	4.0	4.1	.1
OIL	43	6.7	82	2,225	4.3	4.6	.3
	44	6.8	82	2,250	4.4	4.7	.3
	45	6.7	82	2,275	4.5	4.7	.2
	46	6.7	82	2,250	4.5	4.7	.2
Average		6.7	82	2,250	4.4	4.7	.3
PLTD ...	47	6.8	80	2,300	2.8	2.8	.0
	48	6.8	80	2,275	2.8	2.9	.1
	49	6.8	81	2,250	2.9	3.0	.1
	50	6.7	81	2,250	2.9	3.0	.1
Average		6.8	81	2,269	2.9	2.9	.1

¹See table 1.²Pressure measurements taken across filter and mist eliminator.